Building upon the Coalition Agents Experiment (CoAX): Integration of Multimedia Information in GCCS-M using IMPACT

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Abstract

The CoAX demonstration was an international effort, sponsored by the Defense Research Projects Agency (DARPA), Defense Science Technology Office (DSTO), Defense Scientific Technical Laboratory (DSTL), and The Technical Cooperation Program (TTCP). CoAX was a collaboration between DoD labs, industry, and academia to showcase the power of software agents to rapidly construct and maintain a coalition Command and Control Structure. The CoAX demonstration was conducted through numerous Technology Integration Experiments (TIEs). The purpose of the TIEs was to pair up participants in the demonstration such that synergistic effects of software agent technology being developed by each participant could be demonstrated. The Naval Research Laboratory and the University of Maryland participated in a TIE which demonstrated the integration of the NRL Global Command and Control System Maritime (GCCS-M) surrogate with the Interactive Maryland Platform for Agents Collaborating Together (IMPACT) system. This paper will describe the CoAX demonstration, the TIE that was conducted between NRL and UMD, and future interactions that are designed to facilitate the integration of multimedia information into GCCS-M via IMPACT.

Keywords: Multimedia Applications, Multimedia Interfaces, Reasoning with Multimedia Data

1 Introduction to Coalition Operations

Military coalitions are complex organizations that, in many cases, must be rapidly created and effectively managed as the battlefield dynamics change. Issues such as information security, interoperability between data and systems across geopolitical boundaries, lack of information, and labor-intensive approaches to data collection are a few examples of barriers that must be overcome in order for the coalition to be successful in meeting its objectives. Systems generally exist in stovepipe form, particularly across coalition boundaries, and it is very difficult for them to exchange meaningful data. Not only must a coalition be concerned with data interoperability among its own forces and be able to react to an adversary on the physical battlefield, but it must also have the technology in place to react appropriately in an era when attacks can be carried out in cyberspace.

1. REPORT DATE **MAY 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **Building upon the Coalition Agents Experiment (CoAX): Integration of Multimedia Information in GCCS-M using IMPACT**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,4555 Overlook Ave. SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
International Workshop on Multimedia Information Systems (MIS), Ischia, Italy, 26-28 May 2003.

14. ABSTRACT

The CoAX demonstration was an international effort, sponsored by the Defense Research Projects Agency (DARPA), Defense Science Technology Office (DSTO), Defense Scientific Technical Laboratory (DSTL), and The Technical Cooperation Program (TTCP). CoAX was a collaboration between DoD labs, industry, and academia to showcase the power of software agents to rapidly construct and maintain a coalition Command and Control Structure. The CoAX demonstration was conducted through numerous Technology Integration Experiments (TIEs). The purpose of the TIEs was to pair up participants in the demonstration such that synergistic effects of software agent technology being developed by each participant could be demonstrated. The Naval Research Laboratory and the University of Maryland participated in a TIE which demonstrated the integration of the NRL Global Command and Control System Maritime (GCCS-M) surrogate with the Interactive Maryland Platform for Agents Collaborating Together (IMPACT) system. This paper will describe the CoAX demonstration, the TIE that was conducted between NRL and UMD and future interactions that are designed to facilitate the integration of multimedia information into GCCS-M via IMPACT.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

The U.S. Navy's vision of FORCENET is to integrate networks of sensors, weapons, systems, and platforms together in order to multiply force power. If this is to become a reality, such systems must be easily integrated to share information in ways not imagined, such that barriers associated with the current nature of being stovepipe to data and other systems are overcome. Software agents are being increasingly examined as a potential technology to overcome some of the barriers in making FORCENET a reality, particularly across a coalition command and control structure.

Agent aided information retrieval and decision support has attracted the attention of the agent research community for several years. The concept of large ensembles of semi-autonomous, intelligent agents working together is emerging as an important model for building the next generation of sophisticated software applications. This model is especially appropriate for effectively exploiting the increasing availability of diverse, heterogeneous, and distributed on-line information sources, and as a framework for building large, complex, and robust distributed information processing systems. The development of enabling infrastructure for mobile computing and interoperability among programs residing at distant sites, and new generations of distributed operating systems, will continue to make the construction of systems based on this model much easier. Software agents represent a new paradigm in distributed computing. The notion of autonomous software entities able to work autonomously, or in cooperation with each other, to perform tasks in satisfying its objectives represents a powerful concept. Thus, software agents have been deployed in many commercial, academic, and military domains.

In the following sections, we will describe the CoAX 30-month experiment, explain the TIE interaction between NRL and UMD to support this demonstration, and provide details on future collaboration, particularly building upon the TIE in order to leverage the multimedia capabilities of IMPACT to potentially enhance the GCCS-M Common Operational Picture (COP).

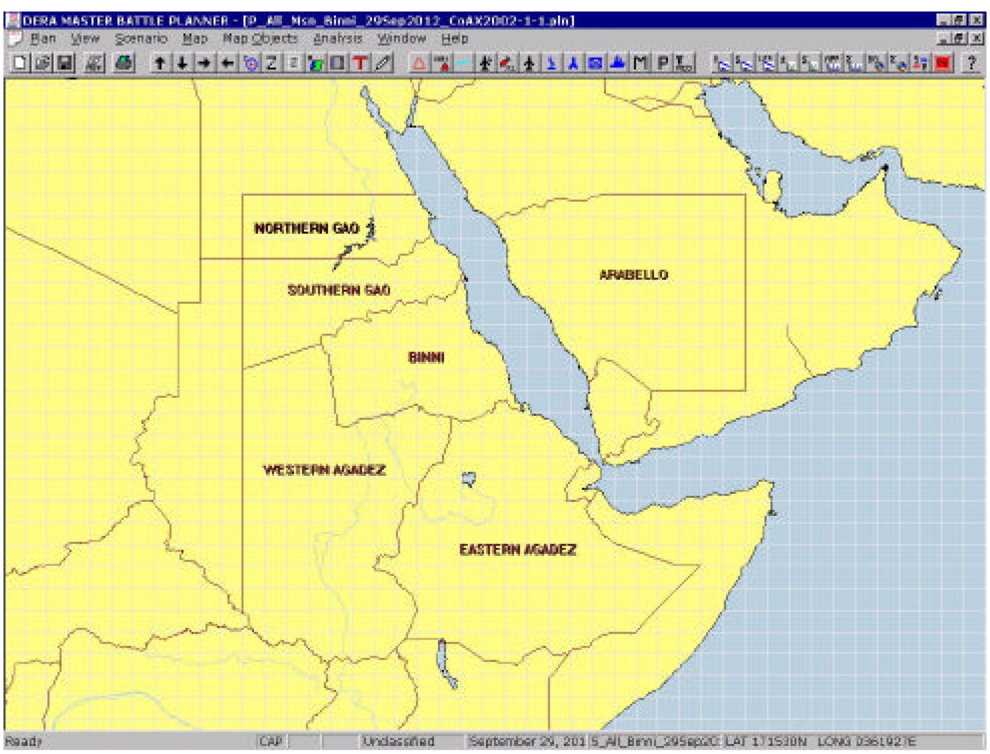

Figure 1: The fictional countries used in the CoAX demonstration

2 Multi-Agents Systems Support for Coalition Agents Experimentation (CoAX)

The Defense Advanced Research Projects Agency (DARPA) has sponsored the Control of Agent Based Systems (CoABS) program [9], one of their largest programs investigating the use of software agents in support of military command and control. The Naval Research Laboratory (NRL) has participated in the Coalition Agents Experiment (CoAX) [10] (a culmination of the CoABS program), an international collaborative effort between DARPA, Defense Science Technology Organization (DSTO), Defense Science Technology Laboratory (DSTL), and The Technical Cooperation Program (TTCP). In addition, DoD laboratories, universities, and industry provided software agent research and technology in order to demonstrate that multi-agent systems are an effective mechanism in fostering coalition interoperability. The scenario chosen for CoAX was based on operational concepts developed by TTCP describing the fictional country of Binni shown in Figure 1. In the scenario, two fictional countries, Agadez and Gao are disputing over Binni due to the geopolitical and economic development of this fictional country. From an operational point of view, a coalition is formed to bring peace to the region, and this coalition is brought together through software agents.

Each of the software agents (approximately 70) representing various functional capabilities of the coalition were incorporated within military domains, for example, the coalition forces maritime component command in Figure 2. The interoperability of the agents was enhanced through the use of ontologies which provided semantic meaning to the information that was exchanged by the agents. Associated with each domain were policies that provided bounds on agent behavior. The enabling technology developed under the CoABS program and utilized for the CoAX demonstration, the CoABS agent grid [9], provided the infrastructure to allow the agents to interface and exchange information with each other. The CoABS agent grid is currently being utilized in joint experimentation programs such as the Navy Expeditionary Sensor Grid Enabling Experiments (the ESG demonstrates the utility of flexibly and dynamically integrating naval sensors and C2 systems via the agent grid), the Air Force Joint Battle InfoSphere, and several Army programs.

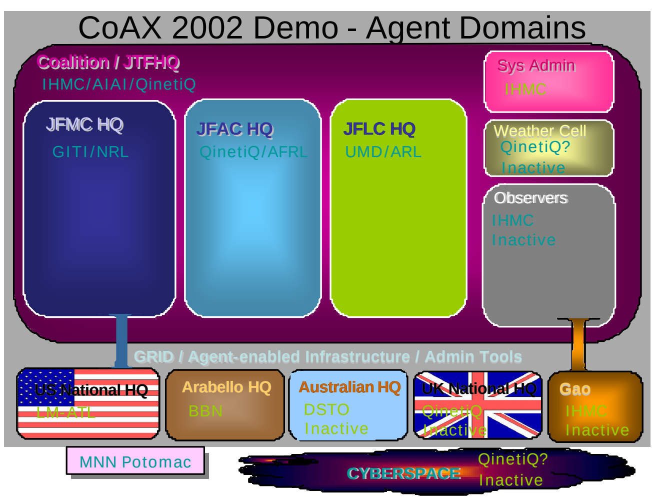

Figure 2: The military domains associated with the CoAX demonstration

The CoAX demonstration was conducted through Technology Integration Experiments, or TIEs. The purpose of each TIE was to pair up certain groups based on the synergistic nature of the technology solutions provided by each of the participants in support of the Binni Scenario.

3 NRL TIE with UMD

The purpose of the TIE collaboration between the University of Maryland (via their IMPACT system) and the Naval Research Laboratory (through their Global Command and Control System Maritime - GCCS-M - surrogate) was to demonstrate the capability of tracking and predicting the location of enemy submarines via agents. Before discussing the details of the TIEs, it is important to set the stage by describing what transpired in the Binni scenario.

In the scenario, both Agadez and Gao are in dispute over Binni, with Agadez becoming increasingly desperate over the territory. Because of this desperation, they launch a missile strike against an Australian ship in the Red Sea. This strike injures many on board and damages critical capabilities on the ship, including the Magnetic Anomaly Detection systems (MAD detectors). As the coalition becomes aware of the strike and subsequent damage, mobile medical monitoring agents are dispatched to the ship to collect injury reports contained in medical databases. From these reports, agents are able to work cooperatively to schedule the evacuation of those critically injured. A neutral country on the eastern coast of the Red Sea, Arabello, agrees to offer its ASW (Anti-Submarine Warfare) capabilities to track down and neutralize the Agadez submarines. These ASW capabilities are rapidly integrated via agents with the coalition systems already in place, and expeditiously begin to provide contact reports on the possible locations of the Agadez submarines. With regard to Figure 3, the Information-Trust-Evaluator (ITE) agents from the University of Texas assign a confidence value to each ASW report. Once these confidence values have been assigned, NRL database agents communicate with the ITE agents to pull and store the reports in the simulated Track Database Manager (TDBM) server for eventual display in the GCCS-M "surrogate" map view. The user is then able to interact with the map view to request "predictions" on the future state of the tracks from the UMD-Predict agent.

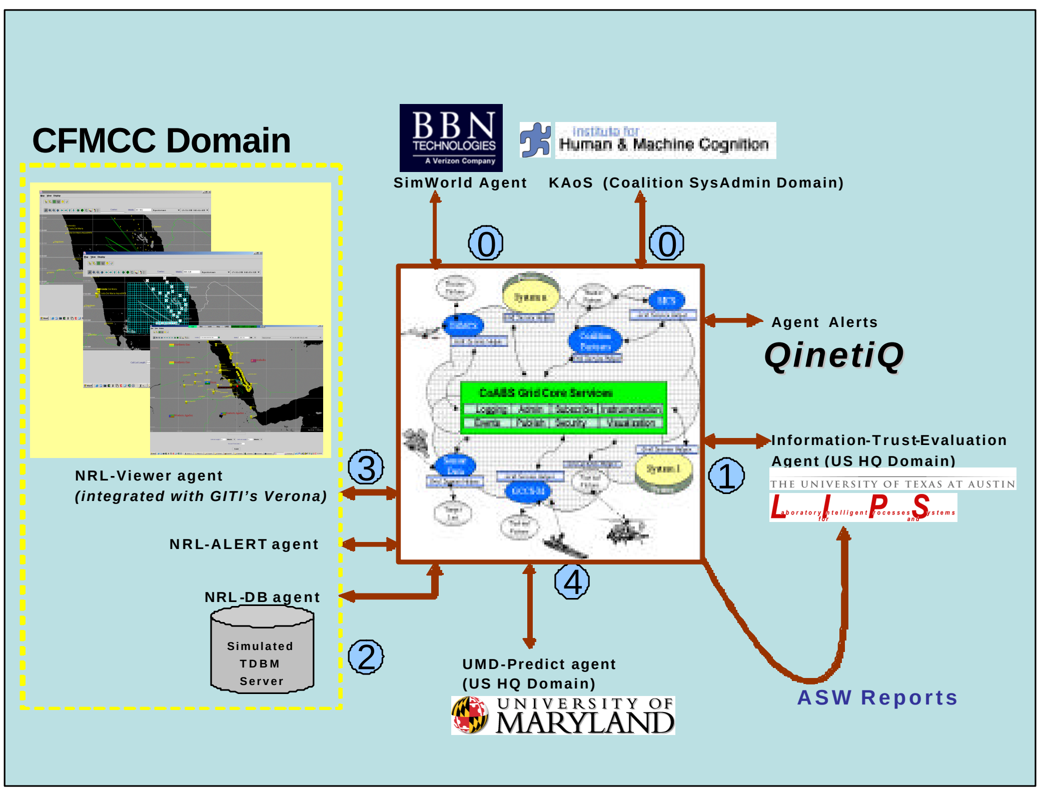

Figure 3: Several TIE components for CoAX

3.1 NRL Technology offered for CoAX

The NRL participated under the military domain of Coalition Forces Maritime Component Command (CFMCC - a major component of CoAX), and interfaced a GCCS-M surrogate to the agent grid. This demonstrated the manner in which software agents would integrate information into the Navy system. Furthermore, the purpose of the demonstration was to show how commanders could interact with such an agent-enabled system to make decisions. The surrogate GCCS-M system was a COTS product called the eXtensible Information System (XIS) [12]. The XIS was chosen for its close functionality to GCCS-M, and is planned as a future segment within the Defense Information Infrastructure (DII) Common Operating Environment (COE).

Using the GCCS-M surrogate and map view, a user, representing a CFMCC staff member, was able to request a prediction on the Agadez submarine tracks from the IMPACT agents. Using the map view, a user was able to draw a rectangular region comprised of an array of cells (this array of cells can be seen in the left image of Figure 4). This information was communicated by the NRL display agent to IMPACT agents which returned a probabilistic value associated with each cell. These values signify the potential future locations of the submarines at a user defined time-instant or time-window. This can be seen in the right image of Figure 4. In this image, one can see a two-dimensional probability distribution in the Red Sea which is returned by IMPACT. The higher (resp. lower) probabilities are shown in red (resp. cyan).

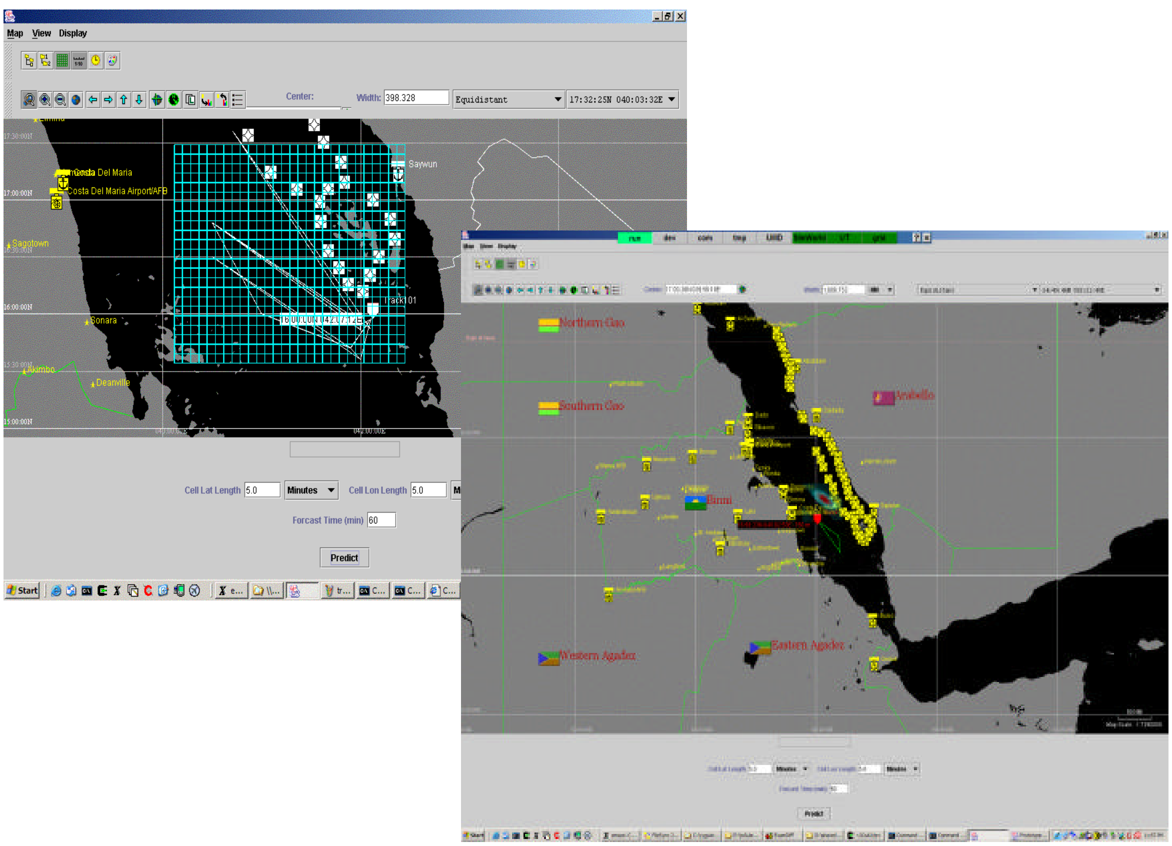

Figure 4: Prediction cells that are sent to the UMD-Predict agent (left) and the results returned by the UMD-Predict agent (right)

3.2 Description of the UMD-Predict Agent

The aforementioned probability distribution was generated by the UMD-Predict agent. This agent was written in IMPACT, the Interactive Maryland Platform for Agents Collaborating Together [1, 7, 8]. IMPACT's powerful libraries made it easy to interpret messages from the CoABS agent grid and to efficiently manipulate the times, positions, velocities, confidence values, probabilities, etc. contained in these messages in order to derive reasonable predictions.

There is a large variety of models that can be used to generate predictions. Some of these models infer future states based on past observations, for example, by fitting a curve through the positions of an Agadez submarine that were reported by an Information-Trust-Evaluator agent. Other models may create forecasts based on the present situation without considering the past. For example, based on the asset locations and priorities specified by a QinetiQ-Intel agent (another agent on the grid providing intelligence reports), one of these models may predict that an Agadez submarine will head toward the closest high-priority asset, regardless of how the sub arrived at its present location. Even if we restrict our attention to models based on curve fitting for the parametric equations X=f(t) and Y=g(t), we can still derive a large number of mutually inconsistent estimates. For example, predictions based on choosing the best fitting line will not, in general, coincide with predictions based on choosing the best fitting parabola. The UMD-Predict agent considered models based on linear, quadratic, cubic, and periodic (sine wave) regression. Also, to help prevent overfitting of the data, the agent supports models that consider only the n most recent observations whose confidence value exceeds a threshold c. For example, model m_1 may determine f(t) and g(t) via linear regression over all past observations while model m_2 may determine f(t) via linear regression and g(t) via quadratic regression over the last five reports that came from sources with a reliability of at least 90%. Furthermore, note that the design of UMD-Predict makes it easy to incorporate new models.

There are many ways to combine a set of models into a single, unified model M. For simplicity, the UMD-Predict agent only considered one of these methods. Specifically, based on several factors such as user-definable parameters and the sum of the squared residuals, each model m was assigned a weight $p(m) \geq 0$ such that $\sum_m p(m) = 1$. Then, for each model m, each location (x, y), and each future instant t, define $p(m, x, y, t)$ as $p(m)$ times the probability, according to m, that the submarine will be at (x, y) during t. Thus $\sum_x \sum_y p(m, x, y, t) = p(m)$ for each model m during each instant t. Next, define $p(M, x, y, t)$ as $\sum_m p(m, x, y, t)$ for each triple (x, y, t). It is easy to verify that $\sum_x \sum_y p(M, x, y, t) = 1$ during each instant t. In other words, the unified model M can be represented by a set of probability matrices where each matrix is associated with a time interval. This set of matrices can be concisely stored in a probabilistic temporal relation [2]. Note that the results returned by UMD-Predict are obtained by modifying M. For example, if the sub cannot reach (x, y) by time t or if the elevation at (x, y) is too high for the sub, then $p(M, x, y, t)$ must be zero. Furthermore, it is usually desirable to smooth the probabilities in each matrix. Theoretically, any modification is acceptable as long as $\sum_x \sum_y p(M, x, y, t)$ remains unchanged for each t.

Ordinarily, UMD-Predict's clients are only interested in a small subset of M. For example, a query may request the portion of the probability matrix for vehicle v at time t that lies within a bounding box b. Also, the client may only be interested in locations that can be covered by an available "sub-killer" at time t (the position, maximum speed, etc. for these sub-killers are provided by the QinetiQ-Intel agent). Additionally, to save bandwidth, clients may only be interested in determining the coordinates of at most n nonoverlapping windows of size $winX$ ´ $winY$ such that the sum of the probabilities in each window exceeds some threshold p.

To summarize, UMD-Predict is an agent that benefits from IMPACT's ability to efficiently handle multimedia data such as sensor reports. The forecasts are obtained by generating a large number of prediction models, combining their estimates into one unified model, transforming this model (e.g., by considering terrain and routing information), and then filtering the results in order to return succinct yet relevant answers. For CoAX, these answers were visualized by NRL agents.

The next sections will describe technology being developed under a separate effort that will be leveraged to allow agents to discover and integrate multimedia information into systems such as GCCS-M and ITEM using the CoABS agent grid.

4 Intelligent Agents in the C4I to Simulation Interface

Having integrated a GCCS-M surrogate in the CoAX demonstration, NRL is currently conducting experiments [5] with the actual GCCS-M, through its integration with the Integrated Theater Engagement Model (ITEM) [5] shown Figure 5. The purpose of this integration is to develop and utilize software agents to decompose planning information and efficiently monitor those plans within ITEM. This work is being sponsored by the Defense Modeling and Simulation Office (DMSO). The hypothesis is that agents integrated with both GCCS-M and ITEM will improve the generation of courses of action (COA) and analysis since these agents will help the user to understand the important cause/effect relationships within the plans via simulation. The planned demonstration will involve integration of the GCCS Ambassador [6], permitting tracks resident in the TDBM to be published to the High Level Architecture (HLA) Run-Time Infrastructure (RTI) [3]. The real and simulated tracks will be presented to agents on the grid through the Critical Mission Data over RTI (CMDR) system [5], which bridges the HLA RTI to the CoABS grid. Software agents are being developed to communicate via the grid to decompose military plans and correlate events in those plans to tracks in order to monitor critical events in the simulation.

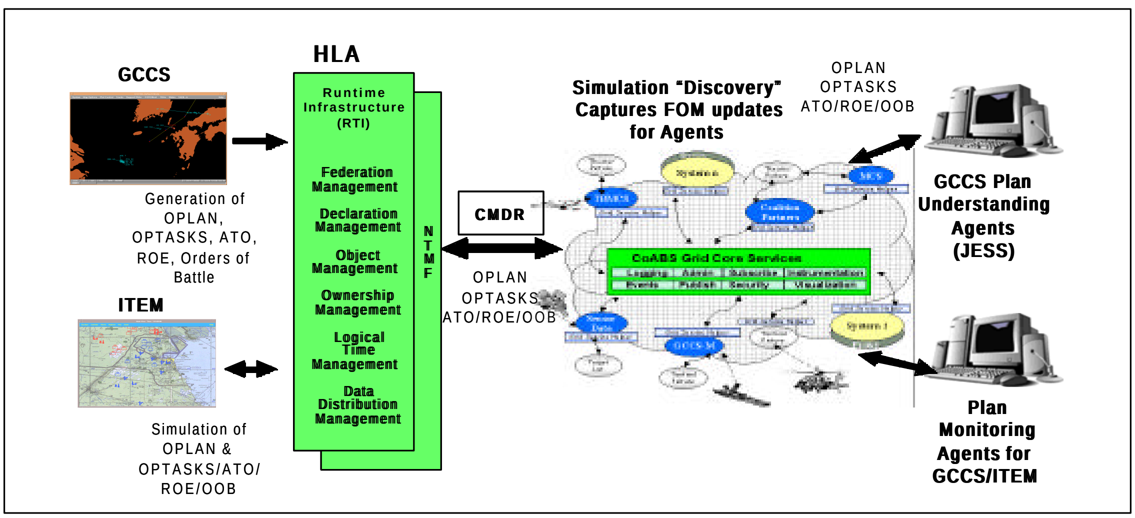

Figure 5: Agent mediated interface between GCCS-M and ITEM.

Plan-understanding agents registered on the grid will be capable of decomposing external planning information, for example, Operational Tasking (OPTASK) messages and Air Tasking Orders (ATO's). This decomposed information will be used to form relationships between events both spatially and temporally, as well as associating the events in the plans to their associated tracks.

The plan-monitoring agents will monitor both ITEM (which represents how entities should be moving and interacting) and GCCS (representing how entities are actually moving and interacting based on a replay of a scenario) in order to take note of the differences that are occurring with regard to critical events and their relationships with other critical events. In other words, the agents will monitor only those events and relationships that are deemed of critical importance with regard to some measurement criteria (e.g., rendezvous points). By measuring deviations in those critical events (and not every deviation occurring in the simulation, since a local deviation does not necessarily imply that a mission will not succeed), the user will be able to more easily comprehend the simulation. Furthermore, the agents can perform notification as the courses of action are performed when the constraints imposed by these relationships/dependencies are violated. In a complex scenario, visual detection of dependencies will be difficult, and automation through software agents will be valuable.

4.1 Benefits of Multimedia Information for GCCS-M

We have described the use of the architecture in Figure 5 to provide plan information from GCCS/ITEM to software agents on the grid. However, it can also be used as a mechanism for agents to gather multimedia from distributed sources and present it to GCCS/ITEM. The CMDR program can be modified to provide that information in the "reverse" direction. This is being considered as a means to integrate multimedia information from IMPACT in both C4I systems and simulation since IMPACT agents can already communicate through the grid.

The GCCS-M system can benefit from the integration of remote multimedia information such as overlays, integration of video, imagery, and formatted textual information. The goal of GCCS is to provide the operational users with a consistent Common Operational Picture (COP), and the integration of such information has the potential to enhance the COP and provide increased situational awareness. Although some capabilities exist in the DII COE architecture (in which the GCCS-M is a "software segment") to permit the integration of a limited set of multimedia information, there is substantially more that exists on the web as well as in legacy systems that may profoundly benefit such systems.

From an operational perspective, the DII COE is still predominantly client-server based. The military is envisioning a paradigm shift from the DII COE environment to Net-Centric Enterprise Services (NCES) [4]. One of the goals of NCES is to leverage commercial object technology, web technology, and web services as well as distributed computing technologies such as network storage and grid computing. These technologies have significantly matured during the past several years and will provide building blocks for NCES while satisfying the design goal of a loose coupling between a broad set of applications with increased levels of interoperability and information sharing. The vision of NCES can profoundly benefit from intelligent agents that are able to discover and tap into distributed multimedia information sources across a network.

4.2 Challenges in Multimedia Integration

There are many challenges when dealing with the integration of multimedia information from the web or legacy systems within critical systems such as GCCS-M. The confidence in the information must be considered, as well as the fusion of that information with information from other similar sources. For example, the fusion algorithm must take into consideration the varying levels of confidence associated with the information in the fusion process. Another issue to consider is that, based on what the user is interested in, how to best present the possible mix of multimedia information to the user. For example, what combination of information provides the most benefit in the context in which the user has requested it? Latency is another concern. For

time-critical applications latency should be minimized, but for rich multimedia information that may be voluminous, there are formidable obstacles that can make it difficult to keep latency sufficiently low. These are some of the challenges that shall be addressed during the integration of multimedia information into IMPACT and GCCS-M/ITEM.

4.3 Multimedia Capabilities of IMPACT

IMPACT supports several mechanisms for acquiring multimedia information. For example, IMPACT agents can reason over sensor data that is acoustic (e.g., from an ensemble of microphones), graphic (e.g., from remotely triggered cameras), gyroscopic (e.g., to track movement direction), seismic (e.g., to supplement passive infrared motion detectors), etc. This data can be obtained from several sources including mobile robots, remote web pages, and dedicated hardware such as Maxim's 1-Wire Weather Station [11]. The utility of handling these kinds of data has been demonstrated, for instance, by IMPACT agents that warn interested users when an engine will probably fail (specifically, when the measurements for the vibration, temperature, or rpm of monitored components exceed their normal range). Similarly, a dispatch agent whose plans depend on the weather may ask a monitoring agent to send a warning whenever the barometric pressure, temperature, humidity, or wind speed of a region exceeds a set of thresholds.

IMPACT also supports several mechanisms for presenting multimedia information. For example, numerical sequences can be visualized by charts in an Excel file that is dynamically generated when an agent triggers the appropriate action. Similarly, there are actions that can dynamically create a PowerPoint (PPT) file by merging slides from existing PPT presentations, filtering out slides that are not of interest, and if desired, inserting objects into slide templates. Furthermore, IMPACT includes actions that can play audio/video files, interact with a remote controlled robot, send an email notification, update a web page, pop-up an alert on a Palm Visor, send a message to a mobile phone that supports SMS (Short Message Service), overlay images onto a map, etc. For example, an IMPACT agent can read a GPS report, determine the relevant zip code, and then feed that information to a web page in order to display live traffic video for an area of interest. Clearly, an important asset of IMPACT is its ability to flexibly handle a large variety of multimedia data.

5 Summary

We have described the CoAX demonstration and the technology offered by NRL and UMD that showcased the manner in which software agents could be used to dynamically integrate information in the form of ASW contact reports within the GCCS-M surrogate. We have also described how a user was able to interact with the surrogate in order to query the agents within IMPACT for a prediction of the future state of enemy submarines. The TIE between NRL and UMD was a critical component in the CoAX experiment that demonstrated how these two systems could be used to end the regional conflict between two disputing countries.

The CoAX experiment successfully showed how software agent technology could be used to integrate (sometimes incompatible) systems together, the utility of policy and domain management facilities to bound agent behavior and facilitate selective sharing of information, and how the ease of composing agent systems together lead to adaptive responses to changes and unexpected events.

We have also disclosed further development and integration efforts (leveraging an ongoing DMSO effort) in order to utilize the multimedia capabilities of IMPACT for enhancing the GCCS-M COP as well as the ITEM simulation. Additionally, we characterized several issues that we plan to address in order to make the integration plausible from an operational perspective.

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ROBERT ROSS is a graduate student at the University of Maryland at College Park. His research focuses on agent systems and the management of imperfect information (i.e., incomplete, inconsistent, imprecise, and uncertain data) in relational, temporal, and spatiotemporal databases.

Note: *It is possible to demo the NRL-UMD TIE without including the other CoAX participants.*